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PREVENTION OF FROST HEAVE IN MANHOLES

Ministry of the Environment
Ontario

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PREVENTION OF FROST HEAVE
IN MANHOLES

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No. 78

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Prevention of Frost Heave in Manholes

Abstract

In an area where the Freezing Index is greater than 500 freezing degree (C)-days, precast concrete manhole sections may separate. A design in which the upper section is attached to the lower section by steel straps bolted at two points was tested. This test, and field observations from other projects, show that the design will minimize heaving due to frost action.

Summary

In an area where the Freezing Index is greater than 500 freezing degree (C)-days, precast concrete manhole sections may separate thus increasing the ground water infiltration rate which in turn increases the load on the sewage treatment plant. Methods are required to counter the thrust due to frost, which causes this damage.

The Ministry of the Environment installed stress and temperature monitoring equipment in four manholes in the Town of Thessalon to (a) determine whether ice lenses impinge on the manhole from outside or grow between the section joints and (b) to provide information leading to a solution to the heaving problem.

Data indicated that a thrust was imposed from the outside rather than being caused by ice lenses growing in the joint. A system by which the upper section was attached to the lower section by steel straps bolted at two points at a calculated distance from the section joints, prevented heaving.

Field observations of similarly designed manholes in other towns confirmed the above conclusions.

Prevention of Frost Heave in Manholes

1.0 General

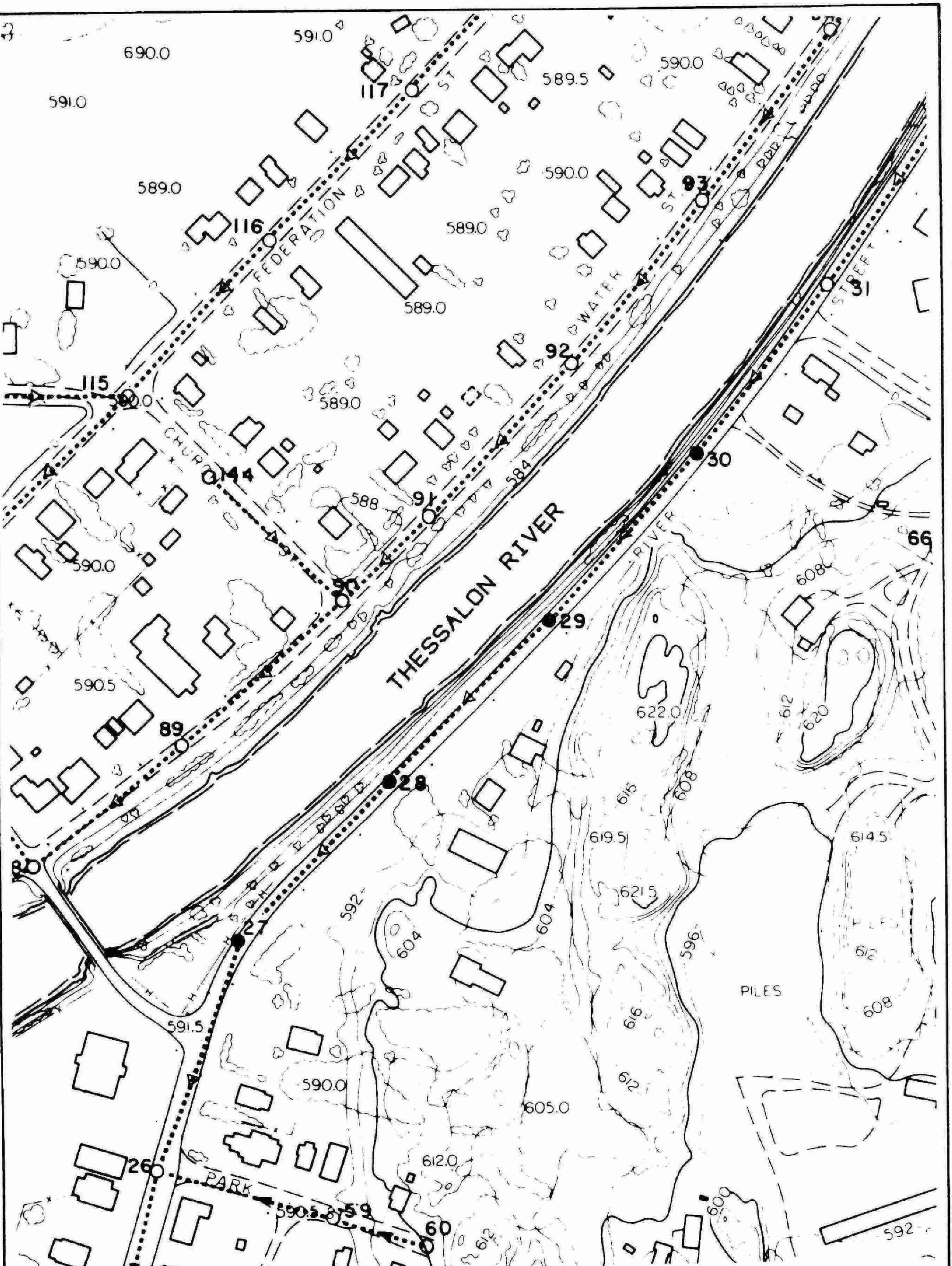
In the Town of Thessalon, at approximately 46°N Latitude, 83° 30' W Longitude, where the winter air temperature drops below -30°C, the Ministry of the Environment installed 11 km of gravity sanitary sewer lines at depths of between 2.5 m and 5 m from the ground surface, two pumping stations and a sewage treatment plant. One hundred and fifty-five precast concrete manholes were installed.

During soil investigations of the area a free water surface was observed in 12 boreholes at depths of between 0.6 m and 2.6 m below the ground surface. It was also found that the site is underlain by very complex deposits of sand, organic silt, varved clay, silty clay, sandy silt till and sometimes rock.

As shown in Fig. 1, manholes #27, 28, 29 and 30, chosen for monitoring, are near the river bank where the ground water level is highest and frost heave is most expected.

2.0 Experimental Work

On each of the above four manholes, several strain gauges (EA-06-20 CBW 120 opt W, supplied by Micromeasurements, a division of Vishey Intertechnology Inc.) were installed on top and bottom of the joints (Fig. 2) to enable the stress direction and magnitude to be monitored. A difficulty in the application of the strain gauges to the manhole wall was caused by moisture seeping into the strain gauges, causing failure. This was avoided by adding 2 mil steel sheet under the gauge backing. Thermocouples made with 20 awg Tex-Tex-20-T wiring (supplied by Thermo-Electric Company) were installed on and along the outside of the manhole to monitor frost depth. Figure 3 shows the relationship between frost depth surrounding the manhole and the freezing index before and after road paving.



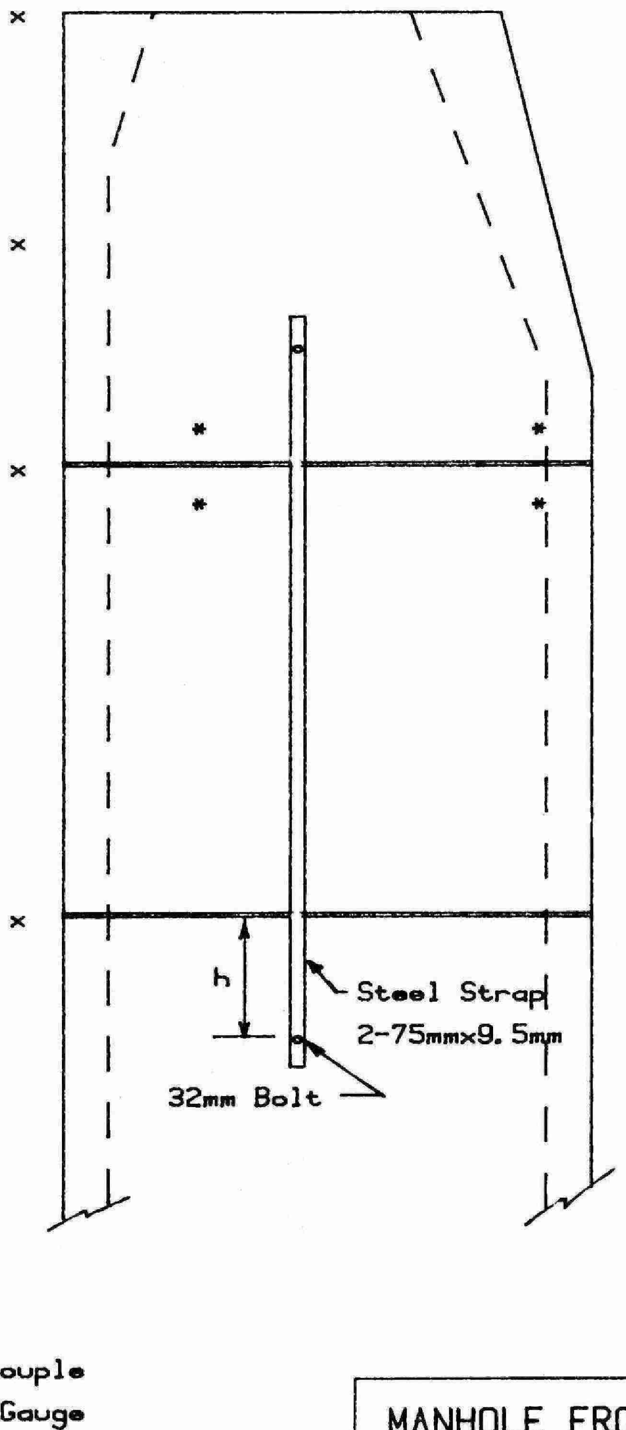
LEGEND

● MANHOLE MONITORED

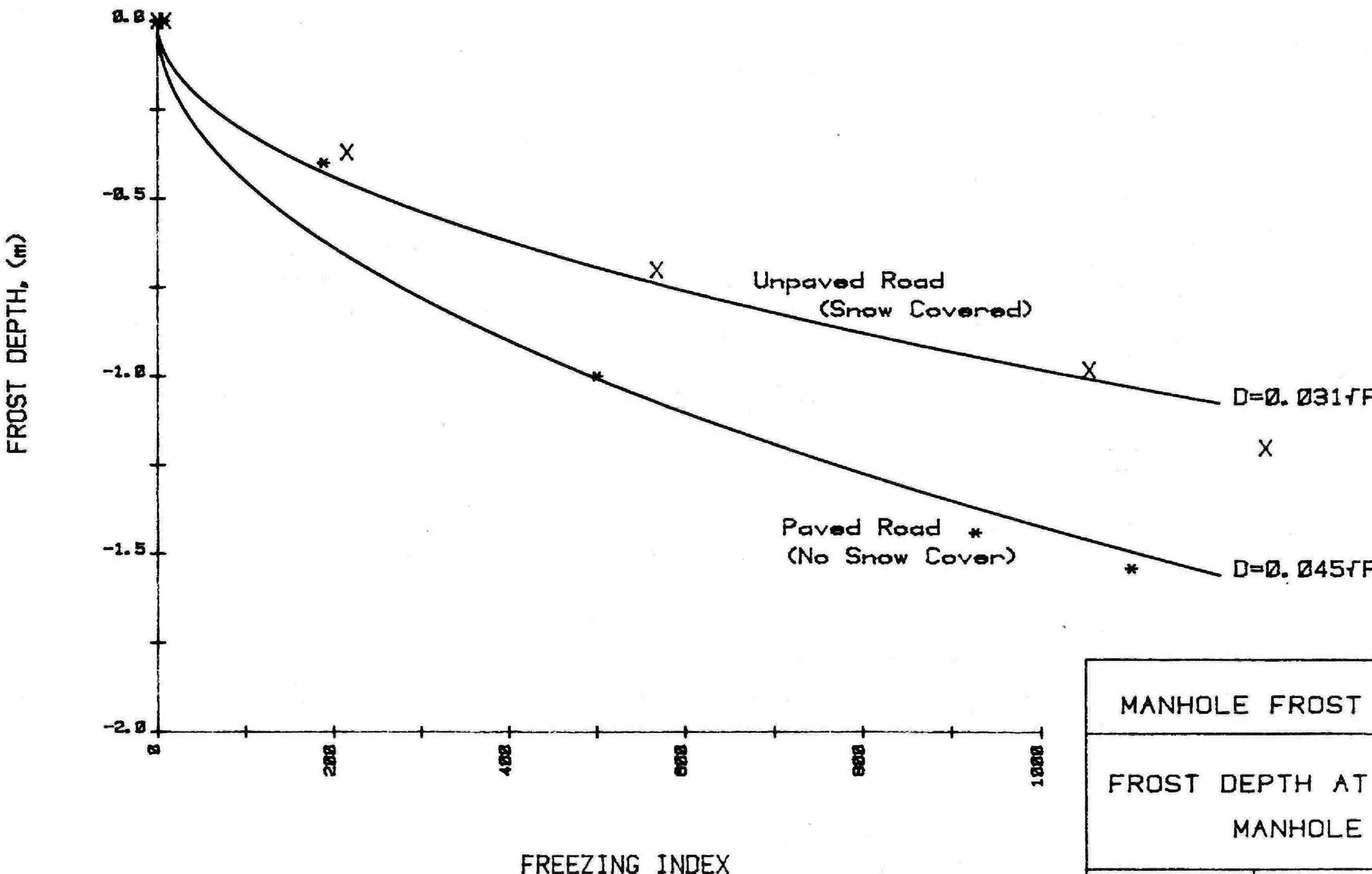
MANHOLE FROST PROTECTION

LOCATION OF
MONITORED MANHOLES

FIG I	1: 2400	JUNE 77



MANHOLE FROST PROTECTION		
THESSALON MANHOLE WITH FROST STRAP		
FIG. 2	N. T. S.	



MANHOLE FROST PROTECTION		
FROST DEPTH AT OUTSIDE OF MANHOLE WALL		
FIG. 3		1978-79

The strain gauge wires ended in a gold plated male Amphenol connector while the thermocouple wires ended in a multijack head. Connectors and multijack heads were installed in boxes on poles near the respective manholes. A warmed mobile container had a P-350 Ak strain indicator with wires connected to a female Amphenol connector and an Elph 111 temperature indicator with wires connected to a multiple plug head.

All manholes including the above four had two steel straps 75 mm x 9.5 mm bolted on the outside of the top and bottom sections through the lift holes. Also a double sheet of 4 mil polyethylene 2 m long covered the top part of the manhole. Only manholes #29 and #30 had the polyethylene cover extended to the bottom and underneath, and the outside walls tarred.

A copy of the form in which strain and temperature readings were recorded is shown in Fig. 4.

3.0 Results and Discussion

It was found by plotting stresses against time in manholes #28 and #30, under bare ground for a period extending over two winters, that a pattern of stress occurred as shown in Figure 5. The pattern of stress indicates a thrust away from the lower section with no opposing thrust in that adjointed lower section. This indicates a frost thrust from outside rather than one due to ice lenses growing in the joint.

Two methods had been used to resist the stress and failed; by installing 0.3 m "frost lugs" in the form of 13 mm diameter steel rods, the ends of which were grouted into adjacent manhole sections at three points on the circumference and by using 0.3 m "frost bolts" attached to the adjacent sections with bolts 160 mm long (Figure 6 & 7).

Note: The use of trade names is for identification only and does not imply an endorsement.

Ministry of the Environment
Ontario

THESSALON MANHOLE FROST PROTECTION PROJECT

Date: Mar 15 - 78
Time: 1PM TO 3.45 PM.
Wind and Precipitation: Very Light - Clear Sky
MIN. TEMP. (8°F)

THERMOCOUPLES

I	20	21	22	23	24	25	26	27	28	29	30	31
	.7	1.3	2.1	2.8	.5	1.6	1.9	1.4	1.5	2.5	3.4	6.2
II	20	21	22	23								
	-.8	—	.7	1.8								
III	20	21	22	23								
	-.4	.2	1.5	2.4								
IV	20	21	22	23								
	-.6	-.5	.6	1.8								

Nearest to Bridge

Furthest from Bridge

Remember sign of strain (+ve or -ve)

STRAIN GAGES

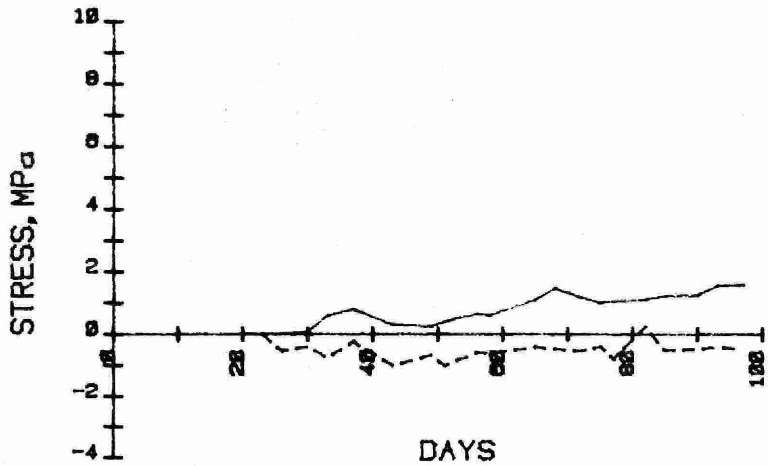
I	1	2	3	4	5	6 ✓	7 ✓	8	9	10 ✓	11	12	13	14 ✓	15
	+ 1431	+ 1658	+ 2375	+ 1466	+ 1457	- 3668	- 0346	+ 0440	+ 0875	+ 0037	+ 0931	+ 1726	-2 6624	- 0293	+ 0144
II	1 ✓	2 ✓	3	4	5	6	7	8	9	10	11 ✓	12	13 ✓	14	15
	-2 4222	- 9946	-4 —	-4 —	- 0190	-4 —	- 9645	-4 —	-4 —	- 9070	-1 3410	+ 0702	- 7745	- 0016	- 0190
III	1	2	4	4	5	6	7	8	9	10	11	12	13	14	15
	-1 0987	-1 5328	-4 —	-2 6567	-4 —	-2 1481	-4 —	-4 —	-3 8226	-4 —	-4 —	-4 —	+ 2453	+ 0782	-4 —
IV	1	2	3	4	5	6 ✓	7	8 ✓	9	10	11	12	13	14	
	-4 —	+ 0752	-4 —	+ 1300	- 0153	- 1482	+ 0370	-3 8560	+ 0738	+ 0266	+ 1404	+ 0911	+ 0560	+ 0407	

Furthest from Bridge

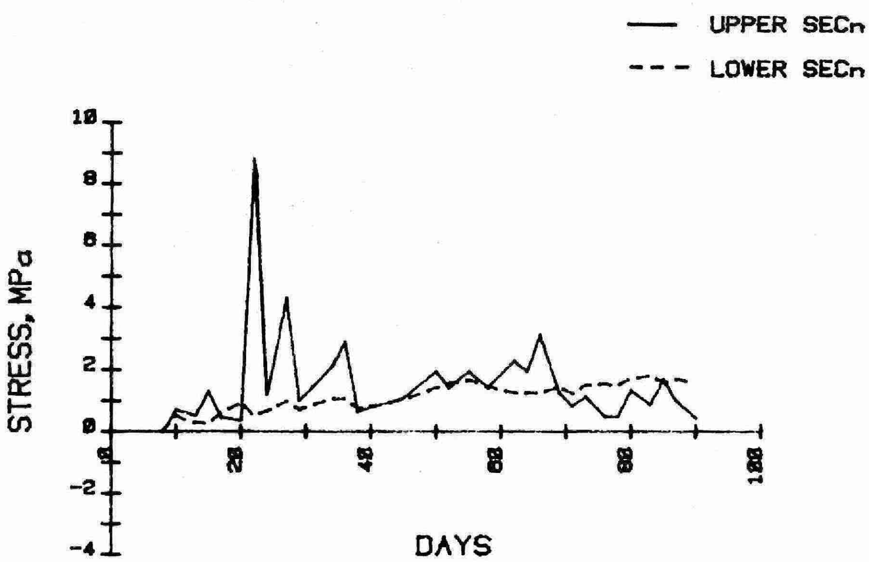
Remarks:

Name:

MANHOLE FROST PROTECTION		
STRAIN AND TEMPERATURE READINGS		
FIG 4		MARCH 1978

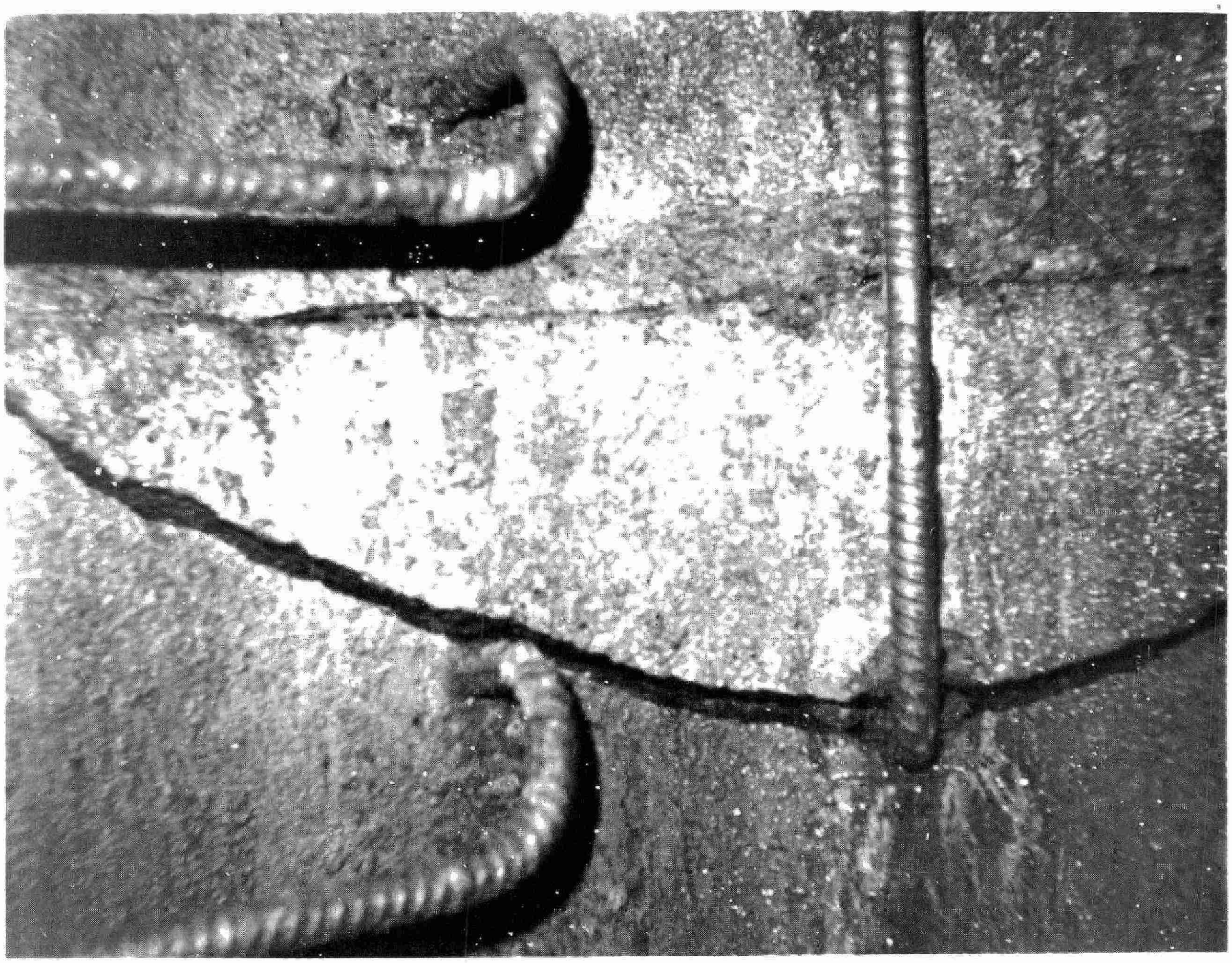


A-MANHOLE #28

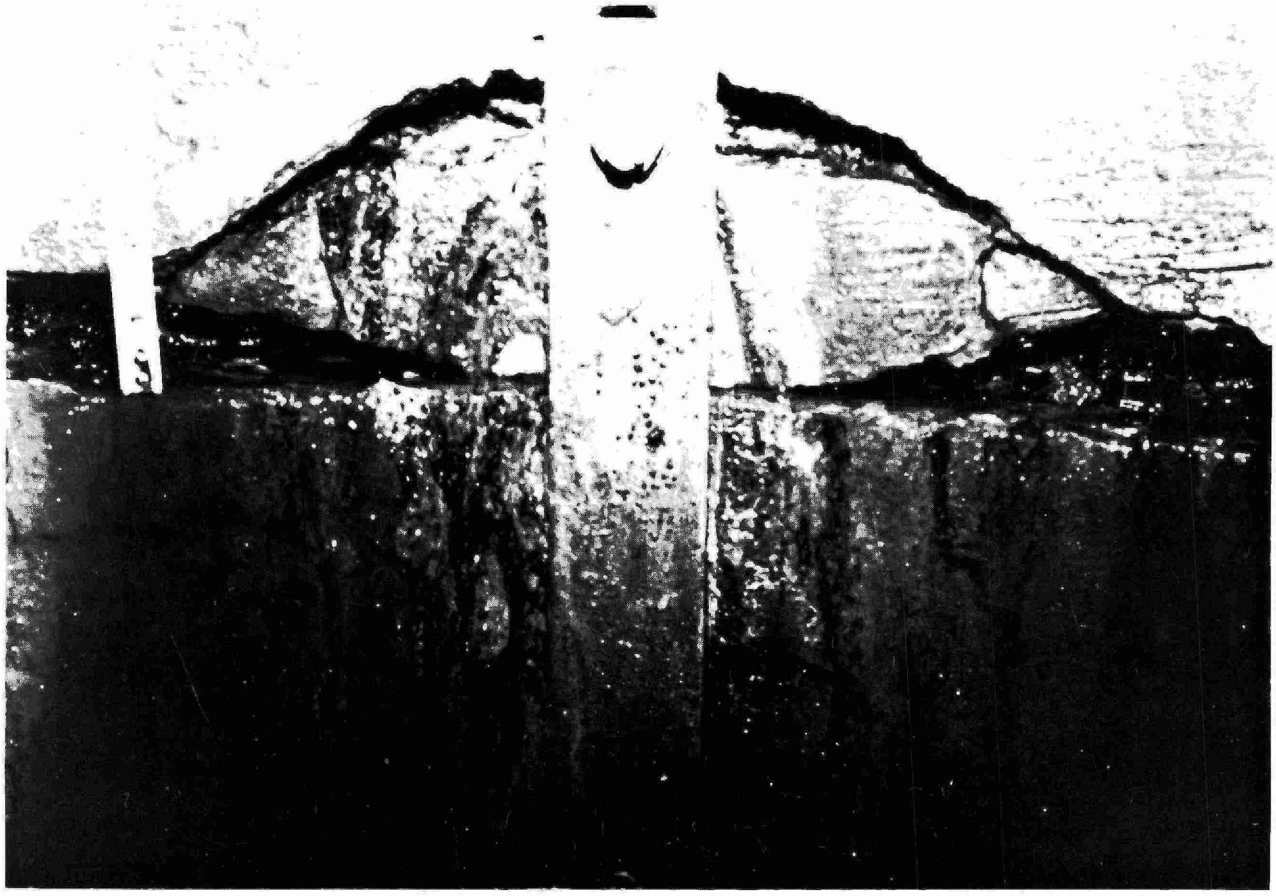


B-MANHOLE #30

MANHOLE FROST PROTECTION		
WINTER STRESS ON MANHOLES		
FIG. 5		1977-78



MANHOLE FROST PROTECTION		
"FROST LUGS" LATCHFORD		
FIG 6		



MANHOLE FROST PROTECTION

"FROST BOLTS"

LATCHFORD

FIG 7

The third method, used in this study, and which proved successful after two winters, uses two or more steel straps, bolted to the top and bottom sections through the lift holes to span the entire length of the manhole.

3.1 Field Data

The following field information from various towns concerning manholes protected by "frost bolts", "frost lugs" or "frost straps" indicates that the straps solved the wall cracking and separation problem.

3.1.1 Town of Thessalon

(Freezing index (F.l.) = 900, manholes installed in June 1977 and designed as shown in Fig. 2).

Inspection after two winters showed that no manhole heaved in cases in which the two strap bolts were installed one above the other. However, in those shallow manholes under bare roads where the strap was installed in an inclined manner or diagonally along the outside wall, separation occurred. In one case (Fig. 8) where on one side of the manhole the strap was vertical and the other diagonal, there was no separation on the vertical strap side but there was on the side of the diagonal strap.

When a manhole was under snow cover no damage was apparent.

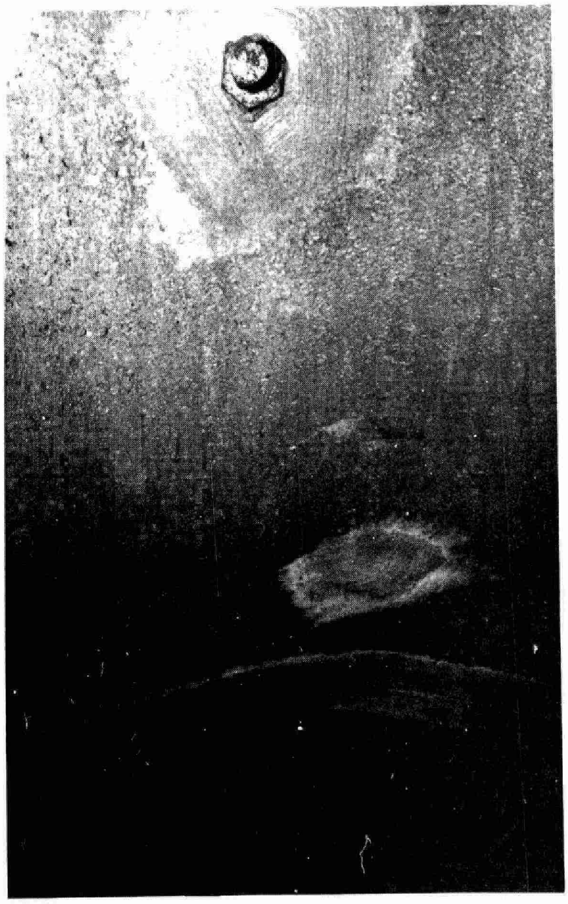
3.1.2 Town of Latchford

(F.l. = 1300, manholes installed in 1975).

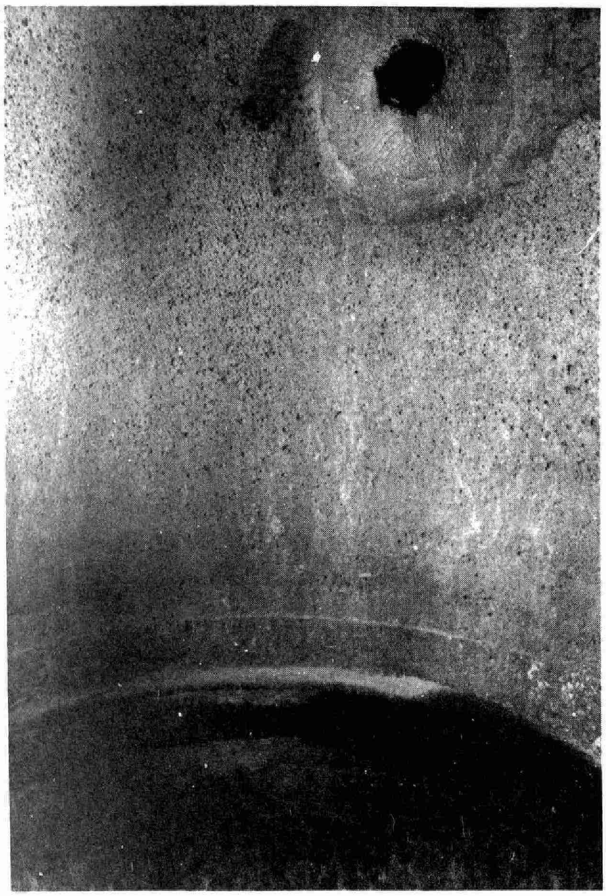
Before the repairs on precast manhole sections were made in the summer of 1976, the concrete walls were cracked mainly around the bolts holding the "frost bolts". The repairs were as follows:

(1) four top-to-bottom steel straps, bolted above and below each joint replaced the 0.3 m "frost bolts" and "frost lugs".

A



B



C

MANHOLE FROST PROTECTION

A - DIAGONAL STRAP : LEAK
B - VERTICAL STRAP : NO LEAK
C - BETWEEN STRAPS
THESSALON

FIG 8		JUNE 78

(2) the outside of the manholes was tarred, and cracks were filled with grout,

(3) the outside of the manholes was wrapped with 2 layers of polyethylene sheet.

During an inspection in May 1977, it was noticed that the repairs prevented about 95% of the infiltration and there were no stress effects around the top-to-bottom steel straps. In May 1978, the manholes withstood the winter except for one that had a separation between the top of the manhole concrete and the brick lip. In May 1979, there was no evidence of further damage to the manholes.

3.1.3 Town of Sundridge

(F.I. = 1050, manholes installed in 1976).

Inspection in May 1977 showed that section walls were cracked; "frost bolts" had been used to join the precast sections (1).

3.1.4 Town of Brighton

(F.I. = 550, manholes installed in 1977 and sections joined with "frost lugs")

Cracks showed up during the May 1978 inspection. In each manhole the "frost lugs" were replaced by two top-to-bottom steel straps. In April 1979, inspection showed that 50% of the repaired manholes had no cracks; the others had very little infiltration, most of which was at the joints.

3.1.5 Town of Stafford

(F.I. = 1000, manholes installed in 1978 with two steel straps spanning the whole manhole length).

Inspection in April 1979 showed no cracks or separation, although 10 cm of road heave due to frost was evident adjacent to the manholes.

3.1.6 Town of Keewatin (Kenora)

(F.I. = 2000, manholes installed in 1976).

Among 100 manholes with sections joined by 13 mm diameter "frost lugs" and wrapped to a depth of 3.1 m with 3.0 mm building paper, then surrounded with a layer of sand 0.3 m thick, down to the bottom only one manhole heaved. It appears that the sand, which did not allow any accumulation of ground water, eliminated ice lens formation. The ground water levels were lower than the bottom of the manhole.

4.0 Theory and Calculations

4.1 The formula (2) used to transform concrete wall strain readings into stress is:

$$\sigma \max = E\,\varepsilon / (1-\mu^2)$$

in which

$\sigma \max$ = maximum stress in the concrete wall direction (M Pa)

E = modulus of elasticity (Young's Modulus) (M Pa)

ε = strain in the wall direction x 10^{-6} (m/m)

μ = Poisson's ratio or transversal unit strain/longitudinal unit strain

- average E for concrete = 23,150 M Pa (3)
- average μ for concrete = 0.2 (3)

4.2 Frost depth surrounding the manhole should be calculated using the following formula:

$$D = A\sqrt{F}$$

where

D = frost depth in metres

F = freezing index in degree (C)-days

A = 0.031 (unpaved road)

= 0.045 (paved road)

4.3 To calculate the minimum distance needed between the strap bolt and the joint if:

r = manhole internal radius (m)

t = wall thickness (m)

H = frost depth (m)

F_{si} = shear stress of ice or interface (kPa)

T = total tension in lug bolts (N)

then the outside area of the manhole in contact with frost

$= 2\pi(r + t)\ H$ and $T \geq F_{si}\ 2\pi\ (r + t)\ \ H$........{1}

Thus the greater the frost penetration, the greater will be the tension in the lugs or bolts.

If it is further assumed that:

F_{ss} = concrete shear stress (kPa)

shear stress is a maximum of 45° from axial load or T (see Fig. 9).

if h = distance between bolt and joint, and

n = number of straps

then $\frac{T}{2n}$ cos 45/(h/cos 45) t = F_{ss} (4)

$$\frac{T}{n}\ (\cos 45)^2 = 2\ F_{ss}\ ht$$

$$T = 4\ n\ F_{ss}\ ht \quad \{2\}$$

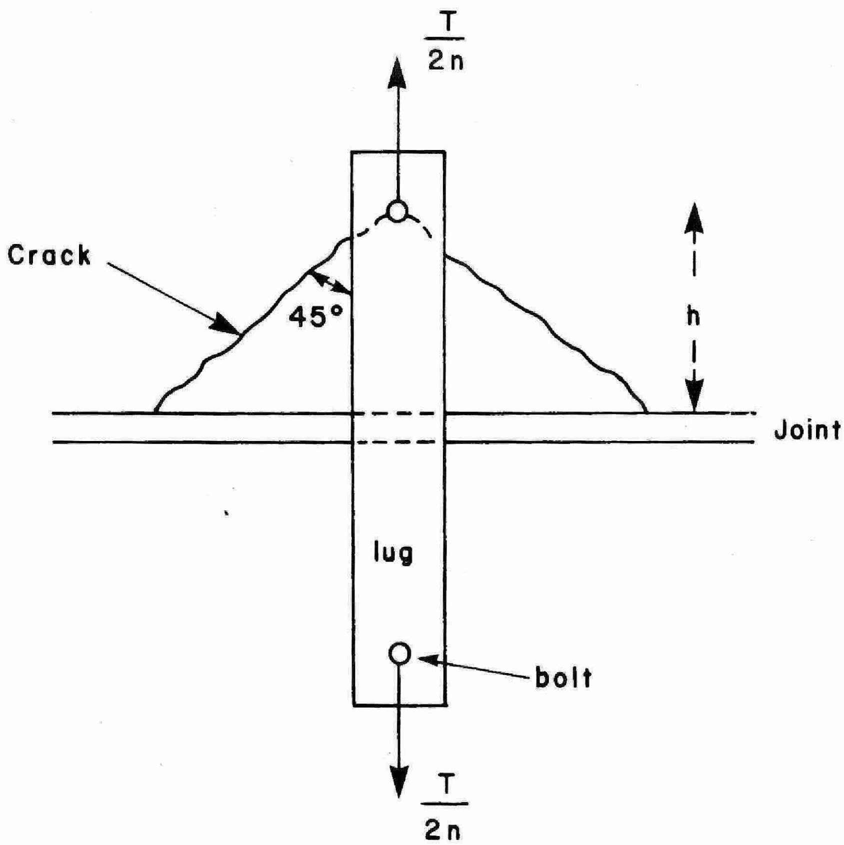
substituting in equation {1}

$$4\ n\ F_{ss}\ ht \geq F_{si}\ 2\pi(r + t)\ H$$

or

$$h \geq \frac{Fsi}{Fss} \cdot \frac{\pi}{n} \cdot \frac{(r + t)}{2\ t} \cdot H$$

Penner and Burn (5) found that the shear strength developed between frost heaving soil and an unheated structure (F_{si}) is between 70 and 85 kPa and for design purposes they recommended 125 kPa. Frederking (6) found the shearing strength of ice, where free water is against a structure, to be 180 kPa.



MANHOLE FROST PROTECTION		
WALL CRACKING		
FIG 9	N.T.S.	

If it is assumed that:

F_{si} = 125 kPa or 125000 N/m^2

F_{ss} = 1380 kPa or 1380000 N/m^2 (3)

n = 2 or 4 straps

r = 0.61 m

t = 125 m

H = .93 m calculated from D = $0.031 \sqrt{F} = 0.031 \sqrt{900}$

= .93 m

T/2n (pull on each bolt) $\geq 125000 \times 2\pi\,(0.61 + 0.125)\quad .93/2n$

$\geq$ 65650 N for 4 straps*

OR $\geq$ 131300 N for 2 straps

h should then be $\geq \dfrac{125000}{1380000} \times \dfrac{3.14}{n} \times \dfrac{(0.61 + 0.125)}{2 \times 0.125} \times .93$

$\geq$ 0.2 m for 4 straps

$\geq$ 0.4 m for 2 straps

This distance between bolt and joint, which depends on concrete quality, is conservative since F_{si} is assumed equal to 125 kPa instead of 85 kPa and the concrete load, which is about 1000 Kg or 10,000 N per precast section, was neglected. In the two towns of Latchford and Sundridge, "h" varied between 0.07 m and 0.12 m in cracked manhole walls with "frost lugs".

4.4 To calculate the strap cross-section let it be assumed that:

strap tensile stress σ = 344500 kPa

since 1 kPa = 10^3 N/m^2

and σ = frost thrust/area of all straps

= 344500 = 65650 x 8 x 10^{-3}/area (m^2)

then area (cm^2) of all straps = 65650 x 8 x 10^{-3} x 10^{4}/344500

= 15.3 cm^2

*1 N = 0.225 lb. force

if $n = 4$ then cross-section of one strap $= 15.3/4 = 3.8\ cm^2$
(use 40 mm x 9.5 mm)

if $n = 2$ then cross-section of one strap $= 15.3/2 = 7.7\ cm^2$
(use 75 mm x 9.5 mm)

4.5 To calculate the bolt diameter, assume that:

bolt shear stress = 206700 kPa

total cross-section of bolts $= 65650 \times 8 \times 10^{-3}/206700\ m^2$
$= 25.5\ cm^2$

cross-section per bolt for 4 straps, 2 bolts per strap $= 25.5/8$
$= 3.2\ cm^2$

bolt diameter $= \sqrt{3.2 \times 4/\pi} = 2$ cm (use 19 mm)

for 2 straps the bolt diameter $= \sqrt{6.4 \times 4/\pi} = 2.9$ cm (use 32 mm)

5.0 Conclusion

The pattern of stress where there was a sealant layer between any two sections of a precast concrete manhole indicated that the top section underwent stress that the lower one did not. This indicates a thrust from outside rather than one such as would be caused by ice lenses growing in a joint and pushing the sections apart, which would cause stress in opposite directions.

A system whereby the top section was strongly attached to the bottom section using steel straps prevented separation. The straps were bolted to the sections at points which were at a distance from the joint greater than the computed minimum required (h).

Field observations comparing similarly designed manholes showed that neither two plies of polyethylene sheet nor a tar layer played vital roles in preventing cracking or separation, while snow cover, which decreases frost penetration, did.

It is noted that in an area of the north where the freezing index is about 1800, an additional precaution that proved successful in avoiding cracks and separation was to add a 0.3 m thick layer of coarse granular material around the manhole. This would be an additional defence against frost, simply by keeping the material around the manhole well drained and hence as ice-free as possible.

6.0 Recommendation

It is recommended that in areas where the freezing index is greater than 500 freezing degree (C)-days, precast manholes should have several steel straps extending vertically from top to bottom and held by bolts in the top and bottom sections.

The number of straps (n) and bolt distance from joint (h), in metres, may be determined by:

$$h \geq (F_{si} / F_{ss}) \cdot (\pi / n) \cdot (r + t)/(2t) \cdot H$$

in which

F_{si} = shear stress of interface (80 to 125 kPa)
F_{ss} = shear stress of concrete (1400 kPa)
H = frost depth in metres
r = manhole internal radius in metres
t = manhole wall thickness in metres

When the design freezing index equals or exceeds 1800 freezing degree (C)-days, an additional granular water draining layer at least 0.3 m thick may surround the manhole.

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